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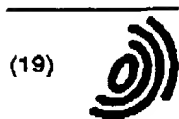
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(54) **Real-time image enhancement techniques**
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GB-A- 2 182 821

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Description**Background Of the Invention****1. Field of the Invention**

[0001] The invention relates generally to image enhancement techniques, and more specifically to real-time image enhancement methods which are performed on textual and/or color photographic images.

2. Description of the Prior Art

[0002] Image enhancement is a process by which acquired image data values are manipulated. Such manipulation is typically directed to improving the appearance of the data as perceived by humans, and/or to render the data more suitable for machine analysis of the image. Image enhancement processes are distinguishable from image restoration processes in that one objective of restoration processes is to improve the fidelity and/or accuracy of a reproduced image with respect to the original image, whereas enhancement processes place greater emphasis on human visual perception and/or the suitability of the processed image for computer analysis.

[0003] Various image enhancement processes have been developed for improving the perceived clarity, intelligibility, and/or quality of images. These image enhancement processes attempt to render images more pleasing to human eyes, irrespective of whether or not these images are accurately reproduced. Oftentimes, a distorted image is more pleasing to the human eye than a perfectly reproduced copy of the original image. For example, if overshoot or undershoot is incorporated into the edges of an image, the resulting image is typically perceived as being more pleasing than an image without such undershoot or overshoot.

[0004] Many prior art image enhancement processes have focused on the improvement of gray-level images, but a direct extension of these processes into the color domain results in degraded or suboptimal images. At the present time, there is a notable lack of image enhancement techniques which are optimized for use in conjunction with color images. The widespread distribution of color images, the growing popularity of multimedia applications, the current proliferation of personal computing devices, and the development of high-definition television systems all serve to increase the demand for improved color image enhancement methods. Such image enhancement methods should be optimized for use in conjunction with color images, and should not merely constitute the reapplication of a gray-level method to the color domain. Moreover, such image enhancement methods should operate in real time using existing hardware platforms.

[0005] Although it is possible to enhance a color image by applying existing monochrome image enhance-

ment algorithms to each color component (red, green, and blue) individually, as described in GB-A-2 182 821, the resulting image may not be enhanced optimally. Image distortion will result if the red, green, and blue components are not properly recombined after the monochrome image enhancement algorithms are applied. Moreover, image distortion will also result if the red, green, and blue components are processed independently, without considering correlation among the components.

Summary of the Invention

[0006] Improved image enhancement methods are disclosed which may be performed on conventional video processing systems. These methods operate in real time to improve the appearance of images as perceived by the human eye, and/or to render these images more suitable for computer analysis. A preferred embodiment enhances color images without degrading the color fidelity of the image.

[0007] According to the preferred embodiment, a color image is represented by a plurality of pixels in HSV (hue, saturation, and intensity) color space. The color image exhibits a finite range of intensity values and a finite range of saturation values. The image is enhanced by applying a first transformation function to the intensity components of the image and a second transformation function to the saturation components of the image. The first transformation function transforms the range of intensity values in the image to correspond to the entire dynamic range of intensity values available in the video processing system. The second transformation function transforms the range of saturation values in the image to correspond to the entire dynamic range of saturation values available in the video processing system. The transformation functions provide an enhanced image having fully optimized intensity and saturation components. The enhanced image is provided by optimally allocating the available dynamic range of intensity and saturation values of the video processing system. Saturation and intensity are enhanced to their extremes without the introduction of color distortion.

Brief Description of the Drawings

[0008] The file of this patent contains at least one drawing executed in color. Copies of this patent with color drawing(s) will be provided by the Patent and Trademark Office upon request and payment of the necessary fee.

FIG. 1 is a graphical representation of a transformation function for mapping the intensity components of a color image;
FIG. 2 illustrates intensity components for an exemplary color image comprised of a plurality of pixels;
FIG. 3 is a histogram showing the relative distribu-

tion of intensity components for the image of FIG. 2; FIG. 4 is a color pictorial representation showing the application of the color image enhancement procedures disclosed herein to an illustrative image; FIG. 5 is a pictorial representation showing the application of the gray-scale image enhancement procedures disclosed herein to an illustrative optically-scanned document; FIG. 6 is a graphical representation of a transformation function for mapping the Cr chroma component of a color image; and FIG. 7 is a graphical representation of a transformation function for mapping the Cb chroma component of a color image.

Detailed Description of the Preferred Embodiments

[0009] The image enhancement methods disclosed herein are directed to improving the appearance of images as perceived by the human eye, and/or to render these images more suitable for computer analysis. A first preferred embodiment enhances color images without degrading image fidelity, and a second preferred embodiment enhances scanned gray-level document images by decreasing the blurring of the image and by increasing the contrast between light and dark regions of the image. Presently-existing video processing systems can perform the image enhancement methods disclosed herein in real time. Suitable video processing systems may include, for example, a microprocessor and a video memory, both of which are present in conventional video telephones such as the AT&T Picasso Still-Image Phone. The AT&T Picasso Still Image Phone is disclosed in copending U. S. Patent application Serial Number 08/202608.

[0010] With respect to the first embodiment, a color image can be enhanced much more effectively in HSV (hue, saturation, and intensity) color space than in RGB (red, green, and blue) color space. In HSV color space, the color information (hue) is isolated and removed from the remaining image components (saturation and intensity). In this manner, saturation and intensity may be enhanced to the maximum extent possible, without introducing distortion into the color (hue) component. Any color image may be represented by a plurality of pixels in HSV (hue, saturation, and intensity) color space. For example, well-known methods may be used to convert a conventional NTSC, SECAM, RGB, or PAL video signal into HSV color space. In some cases, this conversion process is implemented by performing relatively simple computations, but in other cases, nonlinear mathematical operations are required. Such nonlinear operations are computationally expensive. Therefore, the immediately following description will consider image enhancement in the context of HSV color space, after which image enhancement in other color spaces will be discussed.

[0011] Every color image exhibits a finite range of in-

tensity values and a finite range of saturation values. Moreover, in HSV space, these intensity and saturation values are specified as individual components of the image. Conventional video processing systems are equipped to process a finite range of intensity values, as well as a finite range of saturation values. However, the range of intensity values present in the image is not necessarily identical to the total dynamic range of intensity values which conventional video processing systems are equipped to process. Similarly, the range of saturation values present in the image is not necessarily identical to the total dynamic range of saturation values which conventional video processing systems are equipped to process.

[0012] Typically, the available dynamic range of the video processing system is much wider than the range of intensity and saturation values included in a color image. Therefore, unless image enhancement methods are applied to the image, only a portion of the available dynamic range of the video processing system will be utilized. If the image is underexposed, the intensity values of the image are clustered towards one extreme of the available dynamic range of the video processing system, and remaining portions of the dynamic range are relatively underutilized. If the image is overexposed, the intensity values of the image are clustered towards another extreme of the available dynamic range, and remaining portions of the dynamic range are likewise underutilized.

[0013] A first transformation function is applied to the intensity values of the image to optimally utilize the available intensity value dynamic range of the video processing system. A second transformation function is applied to the saturation values of the image to optimally utilize the available saturation value dynamic range of the video processing system. The hue values of the original image are not changed. The purpose of the first transformation function is to allocate the dynamic range of intensity values provided by the video processing system to optimally correspond to the dynamic range of intensity values included in the original color image. The second transformation function allocates the dynamic range of saturation values provided by the video processing system to optimally correspond to the dynamic range of saturation values included in the original color image.

[0014] The first transformation function is a piece wise linear mapping function in two dimensions having three substantially linear regions defined by four intensity value points. A first dimension represents intensity input values (i.e., intensity values included in an image to be processed), and a second dimension represents intensity output values (i.e., optimized intensity values for the enhanced image). A first intensity value point is represented by the minimum intensity value in a given image, a second intensity value point is represented by the maximum intensity value in this image, and the third and fourth intensity value points are selected to be between

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the first and second intensity value points. Selection of specific values for the third and fourth intensity value points are determined by the extent to which a given image is under- or over-exposed.

[0015] Refer now to FIG. 1, which is a graphical representation of an illustrative transformation function for mapping the intensity components of a color image. Image enhancement is performed by transforming the intensity values of the image using a piece wise linear mapping function 102 for the intensity component. The piece wise linear mapping function 102 consists of three line segments 104, 106, 108. Line segment 104 is defined by points *vmin* and *vlower*, line segment 106 is defined by points *vlower* and *vupper*, and line segment 108 is defined by points *vupper* and *vmax*. *vmin* and *vmax* denote the minimum and maximum intensity levels, respectively, in the original image. *vlower* and *vupper* determine the dynamic range allocation for lower, intermediate, and higher ranges of intensity levels.

[0016] The range of intensity values in the original image specifies values for *vmin* and *vmax*. The values of *vlower* and *vupper* are then selected to optimize image enhancement for a given image, based upon the characteristics of the image to be enhanced. For example, if the original image to be enhanced is under-exposed, *vlower* and *vupper* should be selected with a view towards enhancing lower intensity levels. Therefore, a greater proportion of the available dynamic range of the video processing system should be allocated to the lower intensity range. Such an allocation is accomplished by selecting *vlower* to be relatively close to *vmin*, and by selecting *vupper* to be relatively far away from *vmax*. In this manner, high intensity levels are compressed, and low intensity levels are expanded.

[0017] If the original image is over-exposed, *vupper* should be relatively close to *vmax*, and *vlower* should be relatively far away from *vmin*. In this manner, lower intensity levels are compressed, and high intensity levels are expanded. A greater portion of the video processing system's dynamic range will then be allocated to higher intensity levels.

[0018] FIG. 1 includes an identity mapping function 103 which will be discussed hereinafter in connection with the second transformation function and image saturation values.

[0019] With reference to FIG. 2 and 3, specific calculations for *vupper* and *vlower* may be performed by developing an intensity value histogram for the image to be enhanced. Such an histogram divides the range of intensity values present in a given image, i.e., the range from *vmin* and *vmax*, into a plurality of sub-ranges. For each of the plurality of sub-ranges, the number of pixels in the image having intensity values in this sub-range is determined. The first moment of the histogram may be conceptualized as the "center of gravity" of the histogram. The "center of gravity, i.e. the first moment, may be calculated by using the formula

$$\left\{ \begin{array}{l} \text{First} \\ \text{Moment} \\ \text{of} \\ \text{Histogram} \end{array} \right\} = \frac{\sum_{i=1}^N (h_i * I_i)}{\sum_{i=1}^N h_i}$$

where I_i represents a specific intensity level, h_i is the number of pixels having intensity level I_i , and N is the total number of intensity levels (sub-ranges). For example, intensity level 301 (FIG. 3) may be conceptualized as representing intensity level one (I_1), intensity level 303 may be conceptualized as representing intensity level two (I_2), and intensity level 319 may be conceptualized as representing intensity level ten (I_{10}). In this example, there are ten intensity levels (i.e., ten sub-ranges), so N is equal to 10.

[0020] FIG. 2 illustrates intensity components for an exemplary color image 207 comprised of a plurality of pixels 201, 203, and 205. Each pixel 201, 203, 205 is associated with a specific value representing the intensity component for that pixel. For example, pixel 201 is white, which may be defined as representing a relatively low value of intensity. In this manner, pixel 205, in black, represents a relatively high value of intensity, and pixel 203, in diagonal cross-hatching, represents an intermediate value of intensity with respect to pixels 201 and 205.

[0021] FIG. 3 is an intensity value histogram showing the relative distribution of intensity components for the color image 207 of FIG. 2. The intensity value histogram shows the number of pixels in a given image that have specific intensity values. The y-axis, labelled in "number of occurrences", is in units of pixels, and the x-axis represents intensity levels. In the example of FIGs. 2 and 3, ten different intensity values are employed to represent the pixel intensity values of the image. With reference to FIG. 3, the lowest intensity value is represented by intensity value 301 (shown in white), intermediate intensity values are represented by intensity values 303, 305, 307, 309, 311, 313, 315, and 317, and the highest intensity value is represented by intensity value 319 (shown in black). From the intensity value histogram of FIG. 3, it is observed that the color image 207 includes 48 pixels having intensity value 301, 14 pixels having intensity value 303, 22 pixels having intensity value 305, etc. The first moment of the intensity histogram is the intensity value including the greatest number of pixels which, in the present example, is intensity value 301 having a total of 48 pixels.

[0022] The first moment of the intensity value histogram provides an indication as to the relative over- or under-exposure of a given image. The first moment is closer to *vmin* (FIG. 1) for an underexposed image, and closer to *vmax* for an overexposed image. Based upon the first moment of the intensity value histogram (FIG. 3), two intensity levels, *vlower* and *vupper*, are calcu-

lated such that, as the first moment becomes increasingly closer to *vmin*, *vupper* increases and *vlower* decreases. As the first moment becomes increasingly closer to *vmax*, *vupper* decreases and *vlower* increases.

[0023] Let the full dynamic range of the video processing system be given by [VMIN, VMAX], where VMIN and VMAX correspond to the minimum and maximum intensity values capable of being represented in a given video processing system. In the case where a video processing system consists of a video display device, VMIN and VMAX are selected to correspond to the minimum and maximum intensity values capable of being displayed. Intensity values between *vmin* and *vlower* are mapped linearly to the range [VMIN, VLOWER], where $VLOWER = VMIN + \{(vlower - vmin)/3\}$. Intensity values between *vlower* and *vupper* are linearly mapped to the range of [VLOWER, VUPPER], where $VUPPER = VMAX - \{(vmax - vupper)/3\}$. Intensity values in the range [*vupper*, *vmax*] are linearly mapped to the range [VUPPER, VMAX]. Note that the denominators of the equations for VUPPER and VLOWER include a value of 3. This value is shown for illustrative purposes. Values differing somewhat from 3 may be employed such as, for example, 2.5 or 3.7. Moreover, a different value (i.e., 4.0) may be employed in the denominator of VUPPER, relative to the value employed in the denominator of VLOWER (i.e., 2.3).

[0024] The mapping of the intensity values as described in the immediately preceding paragraphs permits proper allocation of the dynamic range of a given video processing system to the actual range of intensity values present in an image to be enhanced.

[0025] A second transformation function is used to transform the saturation components of the original image into saturation components for the enhanced image. This second transformation function is determined by applying a histogram stretching procedure to a saturation histogram representing the saturation components of the original image. A first saturation value point, *smin*, represents the minimum saturation value in the image, and a second saturation value point, *smax*, represents the maximum saturation value in the image.

[0026] An upper limit of saturation, *supper*, is defined as that saturation level where the area under the saturation histogram from that level to the maximum level of saturation, *smax*, is equal to a small percentage of the total number of pixels in the image. For example, a suitable percentage could be approximately 0.5% of the total number of pixels. Saturation components in the range of *smin* to *supper* are linearly mapped to the entire dynamic range of saturation values [SMIN, SMAX] available in the video processing system. In this manner, small perturbations in the saturation values of pixels are ignored without compromising the integrity of the enhanced image.

[0027] Using the first and second transformation functions, the intensity and saturation values of the original

image are modified. The hue components of the image are not changed, and remain the same from the original image to the enhanced image. The intensity values, as well as the color saturation values, of the original image have been enhanced to the maximum extent practicable for use in the operational environment of an arbitrarily-selected video processing system. The result is an optimally enhanced color image without the introduction of color distortion.

[0028] In some system applications, it may not be feasible to determine the available dynamic range of the video processing system which will be used to perform image enhancement. For example, the dynamic range specifications of the video processing system may be unknown, or it may be desirable to perform image enhancement using any of a plurality of arbitrarily-selected video processing systems, each of which has different characteristics. In such applications, a different set of first and second transformation functions could be employed for each video processing system, wherein each set of transformation functions is optimized for a specific video processing system. Alternatively, one set of arbitrarily-determined transformation functions may be employed, wherein the functions are selected to provide useful transformations for a wide variety of video processing systems, even though the functions are not fully optimized for use with any one system.

[0029] The techniques described in the preceding paragraphs with reference to the first and second transformation functions may be applied to a color space other than HSV, although such an application will not necessarily yield optimum results. The process of converting other color spaces into the HSV domain is often computationally intensive, placing excessive demands on system hardware. For some system applications, such as video telephones which communicate using NTSC video signals, the required computations would mandate the use of undesirably expensive hardware.

[0030] The process of converting a non-HSV color space into the HSV domain introduces other problems in addition to computational complexities. Certain colors in one color space may not be physically realizable in another color space. For example, some colors in the YCbCr color space of conventional NTSC video signals may convert into negative values of color in RGB color space. Such negative values are not physically realizable.

[0031] In view of the foregoing difficulties involved in converting a non-HSV color space into the HSV domain, a method is disclosed for enhancing a color image directly in conventional NTSC YCbCr color space. This method operates in real time and is applicable to any video device which captures color images in an NTSC format.

[0032] The luminance (Y) component of a conventional NTSC signal is enhanced following the procedures described above in connection with the intensity component of the HSV color image. Then, if the chromi-

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nance components Cb and Cr are modified by the same amount as the luminance (Y) component, color saturation will remain the same as in the original image. The fact that the color saturation will remain the same can be verified through mathematical derivations known to those skilled in the art and disclosed in a textbook entitled, *Computer Graphics, Principles and Practice*, by J. Foley et al., published by Addison-Wesley in 1991. However, in order to optimally enhance a color image, the saturation components of the image can be further modified to improve the overall saturation of the image.

[0033] The saturation components of the NTSC image are enhanced by modifying the chrominance components, Cb and Cr, by a greater amount than the amount by which the luminance component, Y, has been enhanced. In other words, the slope of the transformation function applied to the chrominance components (the chrominance transformation function) should be greater than the slope of the transformation function applied to the luminance component (the luminance transformation function). In cases where the luminance component is modified to a relatively large extent by the luminance transformation function, this is an indication that the original image is relatively unsaturated. The modification performed by the luminance transformation function is inversely proportional to the amount of saturation in the original image. Therefore, in cases where the saturation is relatively low, the saturation should be increased proportionally, with reference to circumstances where the saturation is relatively high.

[0034] One technique for measuring the amount by which saturation should be increased is by computing the deviation from linearity of the luminance transformation function. With reference to FIG. 1, the y axis which represented "intensity output" is now conceptualized as representing luminance output levels, and the x axis is now conceptualized as representing luminance input levels. For each of a plurality of luminance levels, the absolute difference between the piece wise linear mapping function 102 and an identity mapping function 103 is calculated. The absolute differences for all of the luminance levels are then summed up to obtain the total deviation from linearity, denoted by *Dev*. Then, the following equation is employed to calculate the value of *Incr*. *Incr* is used to determine the amount by which the chrominance components should be increased: $1.0 < (Incr = Dev / 8000) \leq 2.0$. The value of 8000 in the denominator is a representative value set forth for purposes of illustration. Other numerical values may be employed in the denominator in place of 8000 such as, for example, 7000, which also provides useful performance.

[0035] Refer now to FIG. 6, which is a graphical representation of a transformation function for mapping the Cr chroma component of a color image, and also to FIG. 7, which is a graphical representation of a transformation function for mapping the Cb chroma component of a color image. The slope of the piecewise linear map-

ping function 102 (FIGs. 6 and 7) for the range [lower, upper] (FIG. 1) is multiplied by *Incr* to obtain the slope of the chrominance transfer function. The actual minimum and maximum levels of chrominance in the original image are mapped to the entire chrominance component dynamic range (FIGs. 6 and 7). A white point 105 corresponding to a chrominance level of 128 for both Cr (FIG. 6) and Cb (FIG. 7) is mapped to itself by the chrominance transfer function. Using the luminance and chrominance transfer functions, the luminance and chrominance components values of the original image are transformed to create an optimally enhanced image directly in YCbCr color space. YCbCr color space may be employed in the context of conventional PAL, SECAM, and/or NTSC video signals.

[0036] Another preferred embodiment disclosed herein enhances gray-level textual and/or document images by decreasing the blurring of the image and by increasing the contrast between light and dark regions of the image. These gray-level images may be represented, for example, in NTSC YCbCr color space. A major objective of text image enhancement is to increase the readability of text. Since readability of a text image is determined by the luminance component of the image, this method focuses on enhancing the luminance (Y) component. If the color information present in a given image is very limited, then the chrominance components Cb and Cr may not require any processing. Otherwise, Cb and Cr may be processed as described in the immediately preceding paragraphs.

[0037] Detection of the amount of color information in an image is performed by determining the amount of histogram spread of the Cb and Cr components. If the histogram spread is smaller than a given threshold, i.e., approximately 23, then the text image is treated as a gray-level image and only the luminance component is enhanced.

[0038] One possible approach for textual image enhancement is to stretch the Y histogram to the maximum available dynamic range, thereby enhancing image contrast. Although this approach improves the image, further improvements are possible. Pursuant to the method disclosed herein, the background gray level of the text image is determined. Textual images generally contain a relatively limited number of discrete gray levels, as is the case for binary documents, black text on white background, etc. The background gray level corresponds to a significant peak in the Y (luminance) histogram. Such a luminance histogram is similar to the intensity value histogram, except that pixel luminance values are graphed in lieu of pixel intensity values. The peak in the Y (luminance) histogram is detected by checking the gray level at which the peak detection signal crosses over zero from negative values to positive values. The peak detection signal is generated by computing the difference between the cumulative histogram and a smoothed version of the cumulative histogram, the degree of smoothing determining the sensitivity of the peak

detection.

[0039] For purposes of the present example, the one peak in the Y histogram which represents the background gray level must be detected. This detection process is dependent upon whether the original document (i.e., textual image) has a high gray level background or a low gray level background. For high gray level backgrounds, starting from the maximum gray level in the histogram, the first peak encountered in the histogram is the background gray level. For low gray level backgrounds, starting from the minimum gray level in the histogram, the first peak encountered in the histogram is the background gray level.

[0040] Assume, for purposes of the present example, that the textual image has a high gray level background denoted as *ybk_g*. As stated above, an alternative for locating the background gray level is merely to locate the first peak from the high gray level end of the Y histogram. However, the Y histogram should be smoothed first (using conventional smoothing procedures), otherwise the searching process will locate a peak in a local area having a relatively small perturbation, while entirely missing the larger peak representing the actual background gray level.

[0041] The minimum foreground value of the document, denoted as *ymin*, can be located by examining the Y histogram from its lower gray level end. During the search, the first few minimum values corresponding to a small percentage of total number of pixels are ignored. This small percentage may be in the vicinity of 0.1%, as an illustrative example, thereby allowing the method to skip relatively small perturbations in the observed gray levels of the textual image.

[0042] The contrast of the textual image is enhanced by mapping the Y (luminance) component from [*ymin*, *ybk_g*] to [*YMIN*, *YMAX*], where *YMIN* and *YMAX* are, respectively, the minimum and maximum Y values of the video processing system. Before mapping the Y values, a technique generally known to those skilled in the art as unsharp masking is applied to the Y components of the entire image to remove any blurring from the textual image. Conventionally, this sharpening operation causes the appearance of halos around the text edges, which is not very pleasing to human eyes. Since these halos are caused by overshoots in pixel values above the background gray level, *ybk_g*, the halos can be easily removed using standard methods known to those skilled in the art after mapping the Y values from [*ymin*, *ybk_g*] to [*YMIN*, *YMAX*]. Note that the mapping function should be determined before the unsharp masking is applied to the image; otherwise, the background level cannot be detected correctly and the halos can no longer be removed.

[0043] Due to the fact that the textual image enhancement method described herein takes into consideration the characteristics of the actual textual image, the method effectively removes blurring from the image and maximizes contrast. In addition, if the original and the en-

hanced images are both compressed in a format known to those skilled in the art as JPEG, relatively few blocking artifacts will appear in the enhanced image. Fewer blocking artifacts appear because the enhanced image includes a more uniform background and more uniform foreground gray levels. Although the textual image enhancement method was described in the context of YCbCr color space, the method is also applicable to other color spaces.

[0044] FIG. 4 is a pictorial representation showing the application of the color image enhancement procedures disclosed herein to an illustrative color image. In order to demonstrate the effectiveness of the methods disclosed herein, an illustrative image 400 was manually degraded to provide a test image 402. Illustrative image 400 and test image 402 are in YCbCr color space. First enhanced image 404 is the enhanced image which results when a transfer function is applied only to the Y component of the test image 402. As was predicted above, the color of the enhanced image 404 is not enhanced relative to the test image 402.

[0045] Second enhanced image 406 is the image which results when transfer functions are applied to the luminance and chrominance components of the test image 402. Color distortion, caused by interactions between the various color components, is clearly observed. Some type of color compensation scheme must be used to account for interactions between the various color components, and to remove such color distortion.

[0046] Third enhanced image 408 is the image which results when any of a number of commercially-available image processing software packages are utilized. These software packages generally includes some type of color compensation scheme which accounts for interactions between the various color components. Even though the color is not distorted, these prior art software packages do not provide an optimally enhanced image. [0047] The test image 402 may be optimally enhanced by using the methods disclosed herein, as described above in connection with FIGs. 1-3. Such an optimally enhanced image 410 is shown in FIG. 4. By comparing each of the enhanced images 404, 406, 408, 410 with the illustrative image 400, it is observed that the methods disclosed herein enhance contrast and color saturation to the maximum extent practicable. Moreover, the methods disclosed herein do not provide color distortion.

[0048] FIG. 5 is a pictorial representation showing the application of the gray-scale image enhancement procedures disclosed herein to an illustrative optically-scanned document. Textual image 500 is a portion of an original textual image obtained from an AT&T Picasso Still Image Phone. The AT&T Picasso Still Image Phone is disclosed in copending U.S. Patent application Serial Number 08/202608. Enhanced image 502 was prepared using a Y histogram stretching process as described above, followed by unsharp masking. It is observed that the contrast is not optimized, and that halos

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have been introduced by the masking process. Enhanced image 504 was prepared using the mapping function described above and generated from the detected background gray level. Note that some blurring is present. Enhanced image 506 was prepared using the methods disclosed herein. It is observed that the contrast of the image has been optimized, and the blurring has been removed.

Claims

1. A method of enhancing a color image using a video processing system equipped to represent a dynamic range of intensity values and a dynamic range of saturation values, the method comprising the following steps:

representing the color image by a plurality of pixels in HSV (hue, saturation, and intensity) color space, the color image having a finite range of intensity values and a finite range of saturation values;

applying a first transformation function to the finite range of intensity values and a second transformation function to the finite range of saturation values; the first transformation function transforming the first finite range of intensity values to correspond to the entire dynamic range of intensity values; the second transformation function transforming the finite range of saturation values to correspond to the entire dynamic range of saturation values;

the first and second transformation functions thereby providing an enhanced image having fully optimized intensity and saturation values.

2. A method of enhancing a color image as set forth in Claim 1 wherein the first transformation function is a piece wise linear mapping function in two dimensions having three substantially linear regions defined by four intensity value points; the first dimension representing the finite range of intensity values, and the second dimension representing the dynamic range of intensity values,

the method further comprising the steps of:
defining a first intensity value point as being represented by the minimum intensity value in the image;

defining a second intensity value point as being represented by the maximum intensity value in the image;

and selecting third and fourth intensity value points having values in the first dimension between the first and second intensity value points.

3. A method of enhancing a color image as set forth in Claim 2 wherein the piece wise linear mapping function consists of first, second, and third line segments, the first line segment being defined by points *vmin* and *vlower*, the second line segment being defined by points *vlower* and *vupper*, and the third line segment being defined by points *vupper* and *vmax*, such that *vmin* is the minimum intensity value in the image, *vmax* is the maximum intensity value in the image;

the method further comprising the step of:
selecting *vlower* and *vupper* based upon the relative overexposure or underexposure of the image such that:

if the image is relatively under-exposed, *vlower* is selected to be relatively close to *vmin* and *vupper* is selected to be relatively distant from *vmax*, thereby compressing high intensity values and expanding low intensity levels; and
if the image is relatively over-exposed, *vupper* is selected to be relatively close to *vmax*, and *vlower* is selected to be relatively distant from *vmin*, thereby compressing lower intensity values and expanding higher intensity values.

4. A method of enhancing a color image as set forth in Claim 3 wherein *vupper* and *vlower* are calculated by performing the steps of:

developing an intensity value histogram for the image to be enhanced by dividing the range from *vmin* and *vmax* into a plurality of sub-ranges such that, for each of the plurality of sub-ranges, the number of pixels in the image having intensity values in this sub-range is calculated; the center of gravity of the intensity value histogram being defined as the first moment and being indicative as to the relative over- or under-exposure of the image, such that the first moment is relatively closer to *vmin* than to *vmax* for an underexposed image and relatively closer to *vmax* than to *vmin* for an overexposed image; and

selecting *vlower* and *vupper* such that, as the first moment becomes increasingly closer to *vmin*, *vupper* increases and *vlower* decreases, and, as the first moment becomes increasingly closer to *vmax*, *vupper* decreases and *vlower* increases.

5. A method of enhancing a color image as set forth in Claim 4 wherein *vupper* and *vlower* are calculated by performing the steps of:

defining the full dynamic range of intensity values of the video processing system as [VMIN, VMAX], wherein VMIN corresponds substan-

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- tionally to the minimum intensity value capable of being represented in the video processing system, and VMAX corresponds substantially to the maximum intensity value capable of being represented in the video processing system; linearly mapping intensity values in the range of *vmin* and *vlower* in the first dimension to intensity values in the range of VMIN and VLOWER in the second dimension, where VLOWER = $VMIN + ((vlower - vmin)/m)$, where *m* is a real number in the approximate range of 2 to 4; linearly mapping intensity values in the range of *vlower* and *vupper* in the first dimension to intensity values in the range of VLOWER and VUPPER in the second dimension, where VUPPER = $VMAX - ((vmax - vupper)/k)$, where *k* is a real number in the approximate range of 2 to 4; and linearly mapping intensity values in the range of *vupper* and *vmax* in the first dimension to the intensity values in the range of VUPPER and VMAX in the second dimension.

6. A method of enhancing a color image as set forth in Claim 5 wherein the video processing system consists of a video display device and VMIN and VMAX are selected to correspond to the minimum and maximum intensity values capable of being displayed on the video display device.
7. A method of enhancing a color image as set forth in Claim 5 wherein a second transformation function is used to transform the saturation components of the original image into saturation components for the enhanced image.
8. A method of enhancing a color image as set forth in Claim 7 wherein the second transformation function is determined by applying a histogram stretching procedure to a saturation histogram representing the saturation components of the color image.
9. A method of enhancing a color image as set forth in Claim 8 wherein the histogram stretching procedure includes the steps of selecting a first saturation value point, *smin*, representing the minimum saturation value in the image, and a second saturation value point, *smax*, representing the maximum saturation value in the image.
10. A method of enhancing a color image as set forth in Claim 9 wherein an upper limit of saturation, *supper*, is defined as that saturation level where the area under the saturation histogram from that level to the maximum level of saturation, *smax*, is equal to a small percentage of the total number of pixels in the image.

11. A method of enhancing a color image as set forth in Claim 10 wherein the small percentage is approximately equal to 0.5% of the total number of pixels in the image.
12. A method of enhancing a color image as set forth in Claim 10 wherein saturation components in the range of *smin* to *supper* are linearly mapped to the entire dynamic range of saturation values (SMIN, SMAX) available in the video processing system, whereby small perturbations in the saturation values of pixels are ignored without compromising the integrity of the enhanced image.
13. A method of enhancing a color image as set forth in Claim 10 wherein the intensity values of the image are modified using the first transformation function to provide enhanced image intensity values, and the saturation values of the image are modified using the second transformation function to provide enhanced image saturation values.
14. A method of enhancing a color image as set forth in Claim 13 wherein the hue components of the image to be enhanced constitute the hue components of the enhanced image.

Patentansprüche

1. Verfahren zum Verbessern eines Farbbildes unter Verwendung eines Videobearbeitungssystems, das dazu ausgestattet ist, einen dynamischen Bereich von Intensitätswerten und einen dynamischen Bereich von Sättigungswerten darzustellen, wobei das Verfahren die folgenden Schritte umfaßt:

Darstellung des Farbbildes durch eine Vielzahl von Pixeln im HSV-Farbraum (Farblton, Sättigung und Intensität), wobei das Farbbild einen endlichen Bereich von Intensitätswerten und einen endlichen Bereich von Sättigungswerten hat;

Anwendung einer ersten Transformationsfunktion auf den endlichen Bereich von Intensitätswerten und einer zweiten Transformationsfunktion auf den endlichen Bereich von Sättigungswerten, wobei die erste Transformationsfunktion den ersten endlichen Bereich von Intensitätswerten transformiert, damit er dem gesamten dynamischen Bereich von Intensitätswerten entspricht, und wobei die zweite Transformationsfunktion den endlichen Bereich von Sättigungswerten transformiert, damit er dem gesamten dynamischen Bereich von Sättigungswerten entspricht; wodurch die ersten und zweiten Transformationsfunktionen ein verbessertes Bild liefern, das

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voll optimierte Intensitäts- und Sättigungswerte hat.

2. Verfahren zum Verbessern eines Farbbildes nach Anspruch 1, worin die erste Transformationsfunktion eine stückweise lineare Darstellungsfunktion in zwei Dimensionen mit drei im wesentlichen linearen, durch vier Intensitätswertpunkte definierten Gebieten ist, wobei die erste Dimension den endlichen Bereich von Intensitätswerten darstellt und die zweite Dimension den dynamischen Bereich von Intensitätswerten darstellt,

wobei das Verfahren weiterhin die Schritte aufweist:

einen ersten Intensitätswertpunkt zu definieren, wie er durch den Minimalintensitätswert im Bild dargestellt wird;
einen zweiten Intensitätswertpunkt zu definieren, wie er durch den Maximalintensitätswert im Bild dargestellt wird;
und dritte und vierte Intensitätswertpunkte auszuwählen, die Werte in der ersten Dimension zwischen den ersten und zweiten Intensitätswertpunkten haben.

3. Verfahren zum Verbessern eines Farbbildes nach Anspruch 2, worin die stückweise lineare Darstellungsfunktion aus ersten, zweiten und dritten Liniensegmenten besteht, wobei das erste Liniensegment durch die Punkte *vmin* und *vlower* definiert ist, das zweite Liniensegment durch die Punkte *vlower* und *vupper* definiert ist und das dritte Liniensegment durch die Punkte *vupper* und *vmax* definiert ist, so daß *vmin* der Minimalintensitätswert im Bild, *vmax* der Maximalintensitätswert im Bild ist:

wobei das Verfahren weiterhin den Schritt umfaßt:

vlower und *vupper*, basierend auf der relativen Überbelichtung oder Unterbelichtung des Bildes, auszuwählen, so daß:
wenn das Bild relativ unterbelichtet ist, *vlower* so gewählt wird, daß es relativ nahe an *vmin* liegt, und *vupper* so gewählt wird, daß es relativ entfernt von *vmax* liegt, wodurch hohe Intensitätswerte komprimiert und niedrige Intensitätsniveaus gedehnt werden, und,
wenn das Bild relativ überbelichtet ist, *vupper* so gewählt wird, daß es relativ nahe an *vmax* liegt, und *vlower* so gewählt wird, daß es relativ entfernt von *vmin* liegt, wodurch niedrigere Intensitätswerte komprimiert und höhere Intensitätswerte gedehnt werden.

4. Verfahren zum Verbessern eines Farbbildes nach Anspruch 3, worin *vupper* und *vlower* durch Ausführung der folgenden Schritte berechnet werden:

Entwicklung eines Intensitätswerthistogramms für das zu verbessernde Bild durch Teilung des Bereichs von *vmin* und *vmax* in eine Vielzahl von Unterbereichen, so daß für jeden aus der Vielzahl der Unterbereiche die Anzahl der Pixel im Bild, die Intensitätswerte in diesem Unterbereich haben, berechnet wird, wobei der Schwerpunkt des Intensitätswerthistogramms als das erste Moment definiert wird und indikativ bezüglich der relativen Über- oder Unterbelichtung des Bildes ist, so daß das erste Moment für ein unterbelichtetes Bild relativ näher zu *vmin* als zu *vmax* und für ein überbelichtetes Bild relativ näher zu *vmax* als zu *vmin* ist; und Auswahl von *vlower* und *vupper*, so daß, während das erste Moment sich zunehmend *vmin* nähert, *vupper* zunimmt und *vlower* abnimmt, und, während das erste Moment sich zunehmend *vmax* nähert, *vupper* abnimmt und *vlower* zunimmt.

5. Verfahren zum Verbessern eines Farbbildes nach Anspruch 4, worin *vupper* und *vlower* durch Ausführung der folgenden Schritte berechnet werden:

Definierung des vollen dynamischen Intensitätswertbereichs des Videobearbeitungssystems als [VMIN, VMAX], wobei VMIN im wesentlichen dem Minimalintensitätswert entspricht, der im Videobearbeitungssystem dargestellt werden kann, und VMAX im wesentlichen dem Maximalintensitätswert entspricht, der im Videobearbeitungssystem dargestellt werden kann;

lineare Zuordnung von Intensitätswerten im Bereich von *vmin* und *vlower* in der ersten Dimension zu Intensitätswerten im Bereich von VMIN und VLOWER in der zweiten Dimension, wo $VLOWER = VMIN + ((vlower - vmin)/m)$, wo *m* eine reelle Zahl im Näherungsbereich von 2 bis 4 ist;

lineare Zuordnung von Intensitätswerten im Bereich von *vlower* und *vupper* in der ersten Dimension zu Intensitätswerten im Bereich von VLOWER und VUPPER in der zweiten Dimension, wo $VUPPER = VMAX - ((vmax - vupper)/k)$, wo *k* eine reelle Zahl im Näherungsbereich von 2 bis 4 ist; und

lineare Zuordnung von Intensitätswerten im Bereich von *vupper* und *vmax* in der ersten Dimension zu Intensitätswerten im Bereich von VUPPER und VMAX in der zweiten Dimension.

6. Verfahren zum Verbessern eines Farbbildes nach Anspruch 5, worin das Videobearbeitungssystem aus einem Videobildschirmgerät besteht und VMIN und VMAX gewählt werden, um den Minimal- und Maximalintensitätswerten zu entsprechen, die auf

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dem Videobildschirmgerät dargestellt werden können.

7. Verfahren zum Verbessern eines Farbbildes nach Anspruch 5, worin eine zweite Transformationsfunktion verwendet wird, um die Sättigungskomponenten des Originalbildes in Sättigungskomponenten für das verbesserte Bild zu transformieren.

8. Verfahren zum Verbessern eines Farbbildes nach Anspruch 7, worin die zweite Transformationsfunktion bestimmt ist durch die Anwendung eines Histogrammstreckungsverfahrens auf ein Sättigungshistogramm, das die Sättigungskomponenten des Farbbildes darstellt.

9. Verfahren zum Verbessern eines Farbbildes nach Anspruch 8, worin das Histogrammstreckungsverfahren die Schritte einschließt, einen ersten Sättigungswertpunkt, *smin*, auszuwählen, der den Minimalsättigungswert im Bild darstellt, und einen zweiten Sättigungswertpunkt, *smax*, der den Maximalsättigungswert im Bild darstellt.

10. Verfahren zum Verbessern eines Farbbildes nach Anspruch 9, worin eine Sättigungsobergrenze, *super*, als dasjenige Sättigungsniveau definiert ist, wo der Bereich unter dem Sättigungshistogramm von jenem Niveau zum Maximalsättigungsniveau, *smax*, gleich einem geringen Prozentsatz der Gesamtpixelzahl im Bild ist.

11. Verfahren zum Verbessern eines Farbbildes nach Anspruch 10, worin der geringe Prozentsatz ungefähr gleich 0,5 % der Gesamtpixelzahl im Bild ist.

12. Verfahren zum Verbessern eines Farbbildes nach Anspruch 10, worin Sättigungskomponenten im Bereich von *smin* bis *super* linear dem gesamten dynamischen im Videobearbeitungssystem verfügbaren Bereich von Sättigungswerten [*SMIN*, *SMAX*] zugeordnet werden, wodurch kleine Störungen in den Sättigungswerten von Pixeln ignoriert werden, ohne die Unversehrtheit des verbesserten Bildes zu gefährden.

13. Verfahren zum Verbessern eines Farbbildes nach Anspruch 10, worin die Intensitätswerte des Bildes unter Verwendung der ersten Transformationsfunktion modifiziert werden, um verbesserte Bildintensitätswerte zu liefern, und die Sättigungswerte des Bildes unter Verwendung der zweiten Transformationsfunktion modifiziert werden, um verbesserte Bildsättigungswerte zu liefern.

14. Verfahren zum Verbessern eines Farbbildes nach Anspruch 13, worin die Farbtonkomponenten des zu verbesserten Bildes die Farbtonkomponenten

des verbesserten Bildes bilden.

Revendications

1. Procédé d'amélioration d'une image en couleurs utilisant un système de traitement vidéo équipé pour représenter une gamme dynamique de valeurs d'intensité et une gamme dynamique de valeurs de saturation, le procédé comprenant les étapes suivantes :

la représentation de l'image en couleurs par une pluralité de pixels dans l'espace des couleurs TSV (teinte, saturation, et intensité), l'image en couleurs ayant une gamme finie de valeurs d'intensité et une gamme finie de valeurs de saturation ;

l'application d'une fonction de transformation à la gamme finie de valeurs d'intensité et d'une seconde fonction de transformation à la gamme finie de valeurs de saturation ; la première fonction de transformation transformant la première gamme finie de valeurs d'intensité afin qu'elle corresponde à la totalité de la gamme dynamique de valeurs d'intensité ; la seconde fonction de transformation transformant la gamme finie de valeurs de saturation afin qu'elle corresponde à la totalité de la gamme dynamique de valeurs de saturation ;

les première et seconde fonctions de transformation fournissant ainsi une image améliorée ayant des valeurs d'intensité et de saturation entièrement optimisées.

2. Procédé d'amélioration d'une image en couleurs suivant la revendication 1, dans lequel la première fonction de transformation est une fonction de projection linéaire par morceaux à deux dimensions ayant trois régions sensiblement linéaires définies par quatre points de valeurs d'intensité ; la première dimension représentant la gamme finie de valeurs d'intensité, et la seconde dimension représentant la gamme dynamique de valeurs d'intensité,

le procédé comprenant en outre les étapes de :
définition d'un premier point de valeur d'intensité comme étant représenté par la valeur d'intensité minimale dans l'image ;
définition d'un second point de valeur d'intensité comme étant représenté par la valeur d'intensité maximale dans l'image ;
et sélection de troisième et quatrième points de valeurs d'intensité ayant des valeurs dans la première dimension, comprises entre les premier et second points de valeurs d'intensité.

3. Procédé d'amélioration d'une image en couleurs

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suivant la revendication 2, dans lequel la fonction de projection linéaire par morceaux est constituée de premier, second et troisième segments de droite, le premier segment de droite étant défini par des points *vmin* et *vinf*, le second segment de droite étant défini par des points *vinf* et *vsup*, et le troisième segment de droite étant défini par des points *vsup* et *vmax*, de telle façon que *vmin* soit la valeur d'intensité minimale dans l'image, et que *vmax* soit la valeur d'intensité maximale dans l'image ;

le procédé comprenant en outre les étapes de :
sélection de *vinf* et de *vsup* sur la base d'une surexposition ou d'une sous-exposition relative de l'image de telle façon que :

si l'image est relativement sous-exposée, *vinf* soit sélectionné de façon à être relativement proche de *vmin* et *vsup* soit sélectionné de façon à être relativement éloigné de *vmax*, afin de comprimer ainsi les valeurs d'intensité élevées et de dilater les niveaux d'intensité faibles ; et que

si l'image est relativement surexposée, *vsup* soit sélectionné de façon à être relativement proche de *vmax* et *vinf* soit sélectionné de façon à être relativement éloigné de *vmin*, afin de comprimer ainsi les valeurs d'intensité plus faibles et de dilater les valeurs d'intensité plus élevées.

4. Procédé d'amélioration d'une image en couleurs suivant la revendication 3, dans lequel *vsup* et *vinf* sont calculés par exécution des étapes de :

élaboration d'un histogramme de valeurs d'intensité pour l'image devant être améliorée en divisant la gamme allant de *vmin* à *vmax* en une pluralité de sous-gammes, de telle façon que, pour chacune de la pluralité de sous-gammes, le nombre de pixels dans l'image ayant des valeurs d'intensité se situant dans cette sous-gamme soit calculé ; le centre de gravité de l'histogramme de valeurs d'intensité étant défini comme étant le premier moment et comme étant représentatif de la surexposition ou de la sous-exposition relative de l'image, de façon que le premier moment soit relativement plus proche de *vmin* que de *vmax* pour une image sous-exposée et relativement plus proche de *vmax* que de *vmin* pour une image surexposée ; et
sélection de *vinf* et de *vsup* de telle façon que, lorsque le premier moment se rapproche de *vmin*, *vsup* croisse et *vinf* décroisse, et que lorsque le premier moment se rapproche de *vmax*, *vsup* décroisse et *vinf* croisse.

5. Procédé d'amélioration d'une image en couleurs

suivant la revendication 4, dans lequel *vsup* et *vinf* sont calculés par exécution des étapes de :

définition de la gamme dynamique totale de valeurs d'intensité du système de traitement vidéo comme étant $[VMIN, VMAX]$, où *VMIN* correspond sensiblement à la valeur d'intensité minimale pouvant être représentée dans le système de traitement vidéo, et *VMAX* correspond sensiblement à la valeur d'intensité maximale pouvant être représentée dans le système de traitement vidéo ;

projection linéaire de valeurs d'intensité dans la gamme de *vmin* à *vinf* dans la première dimension, en valeurs d'intensité se situant dans la gamme de *VMIN* à *VINF*, dans la seconde dimension, où $VINF = VMIN + ((vinf - vmin)/m)$, *m* étant un nombre réel dans la gamme approximative de 2 à 4 ;

projection linéaire de valeurs d'intensité dans la gamme de *vinf* à *vsup*, dans la première dimension, en valeurs d'intensité dans la gamme de *VINF* à *VSUP*, dans la seconde dimension, où $VSUP = VMAX - ((vmax - vsup)/k)$, *k* étant un nombre réel dans la gamme approximative de 2 à 4 ; et

projection linéaire de valeurs d'intensité dans la gamme de *vsup* à *vmax*, dans la première dimension, en valeurs d'intensité se situant dans la gamme de *VSUP* à *VMAX* dans la seconde dimension.

6. Procédé d'amélioration d'une image en couleurs suivant la revendication 5, dans lequel le système de traitement vidéo est constitué d'un dispositif d'affichage vidéo et *VMIN* et *VMAX* sont sélectionnés de façon à correspondre à des valeurs d'intensité minimale et maximale pouvant être affichées sur le dispositif d'affichage vidéo.

7. Procédé d'amélioration d'une image en couleurs suivant la revendication 5, dans lequel une seconde fonction de transformation est utilisée pour transformer les composantes de saturation de l'image originale en des composantes de saturation destinées à l'image améliorée.

8. Procédé d'amélioration d'une image en couleurs suivant la revendication 7, dans lequel la seconde fonction de transformation est déterminée en appliquant une procédure d'étalement de l'histogramme en un histogramme de saturation représentant les composantes de saturation de l'image en couleurs.

9. Procédé d'amélioration d'une image en couleurs suivant la revendication 8, dans lequel la procédure d'étalement de l'histogramme comprend les étapes de sélection d'un premier point de valeur de satu-

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ration *smin*, représentant la valeur de saturation minimale dans l'image, et d'un second point de valeur de saturation *smax* représentant la valeur de saturation maximale dans l'image.

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10. Procédé d'amélioration d'une image en couleurs suivant la revendication 9, dans lequel une limite supérieure de saturation *ssup* est définie comme étant le niveau de saturation tel que la superficie sous l'histogramme de saturation, de ce niveau au niveau maximal de saturation *smax*, soit égale à un petit pourcentage du nombre total de pixels dans l'image.

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11. Procédé d'amélioration d'une image en couleurs suivant la revendication 10, dans lequel le petit pourcentage est approximativement égal à 0,5 % du nombre total de pixels dans l'image.

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12. Procédé d'amélioration d'une image en couleurs suivant la revendication 10, dans lequel des composantes de saturation se situant dans la gamme de *smin* à *ssup* sont projetées linéairement sur la totalité de la gamme dynamique des valeurs de saturation [SMIN, SMAX] pouvant être obtenues dans le système de traitement vidéo, de sorte que de faibles perturbations des valeurs de saturation de pixels sont ignorées sans compromettre l'intégrité de l'image améliorée.

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13. Procédé d'amélioration d'une image en couleurs suivant la revendication 10, dans lequel les valeurs d'intensité de l'image sont modifiées en utilisant la première fonction de transformation pour produire des valeurs d'intensité d'image améliorée, et les valeurs de saturation de l'image sont modifiées en utilisant la seconde fonction de transformation pour obtenir des valeurs de saturation d'image améliorées.

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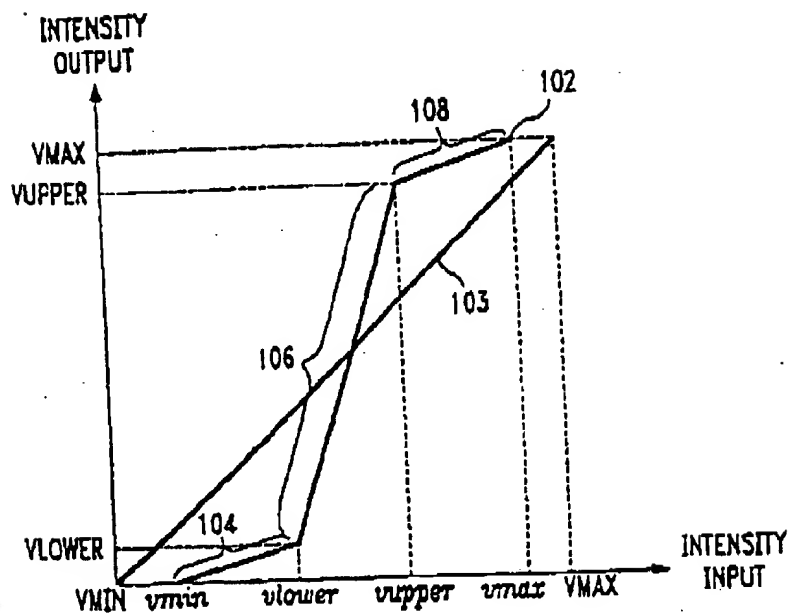
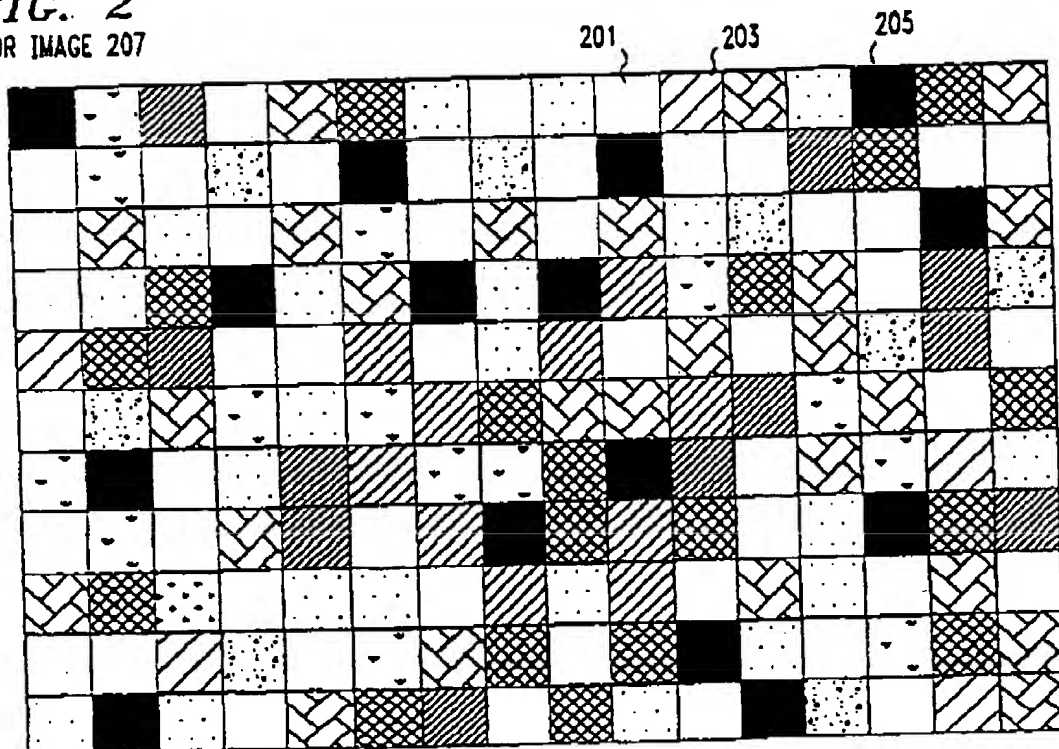
14. Procédé d'amélioration d'une image en couleurs suivant la revendication 13, dans lequel les composantes de teinte de l'image devant être améliorée constituent les composantes de teinte de l'image améliorée.

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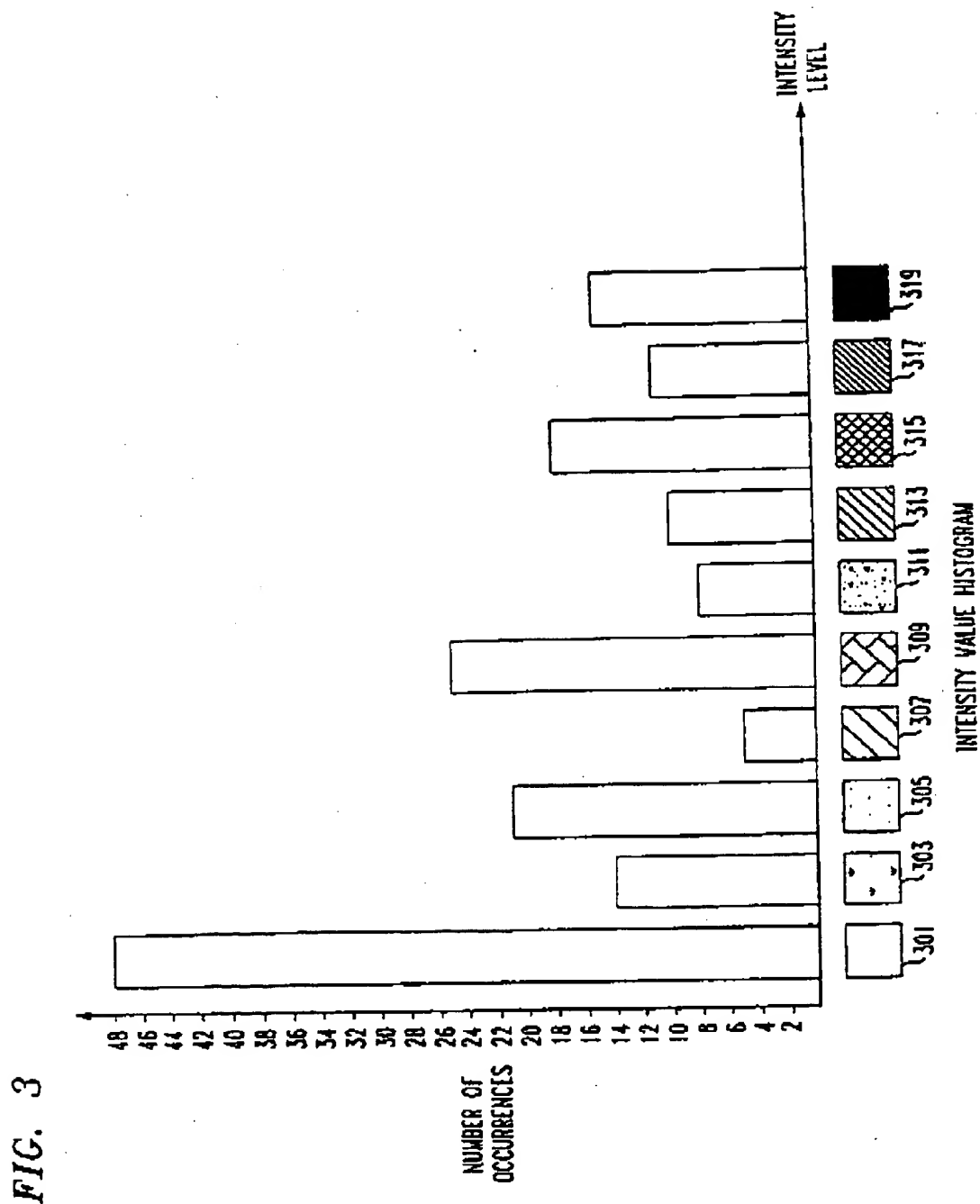
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FIG. 1**FIG. 2**
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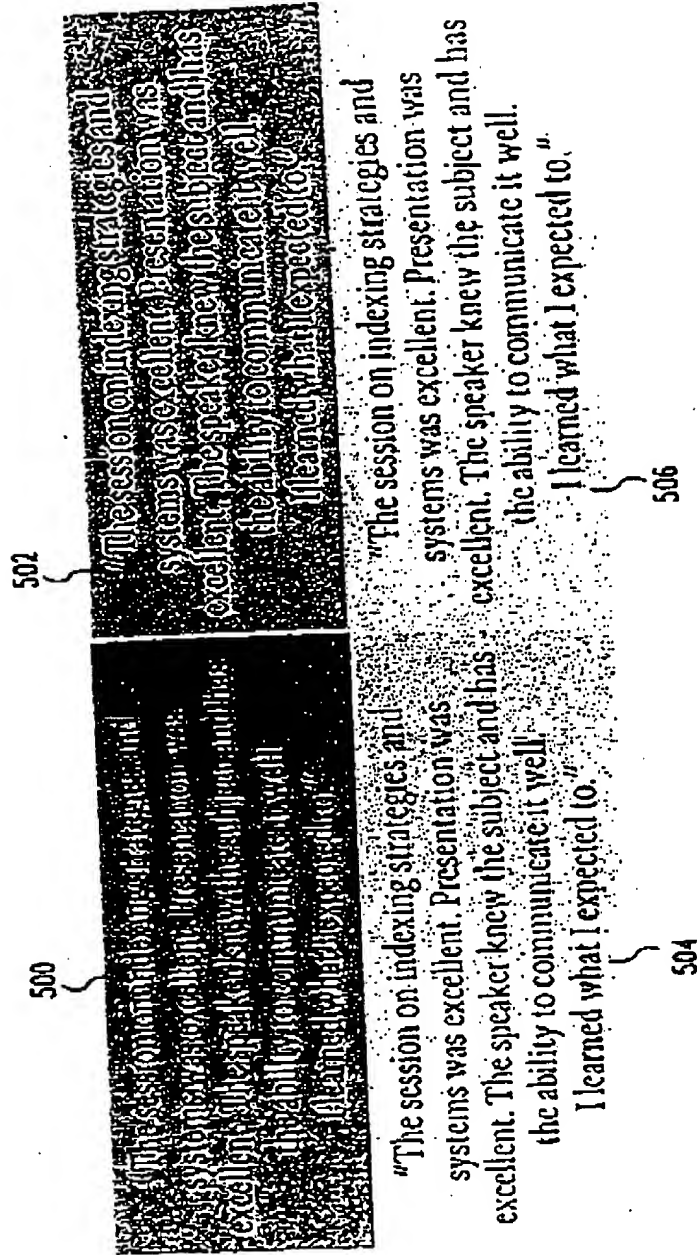
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FIG. 4



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FIG. 5



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FIG. 6

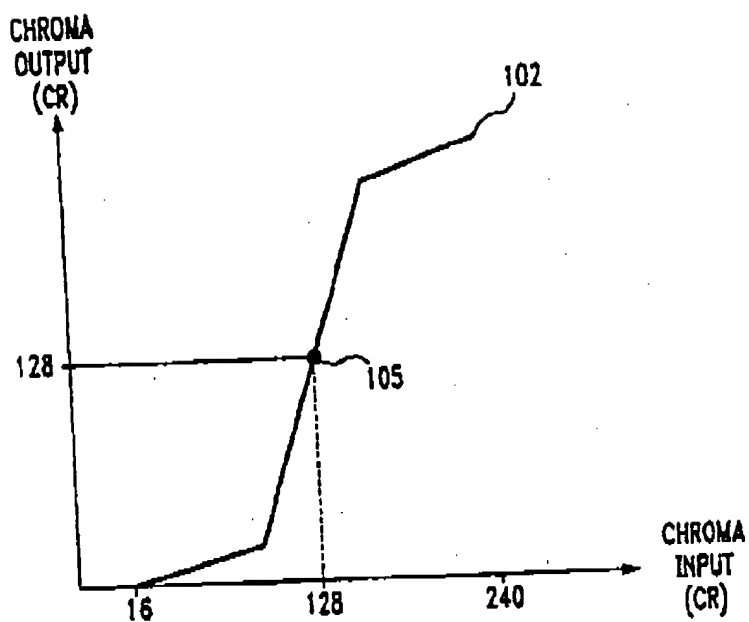
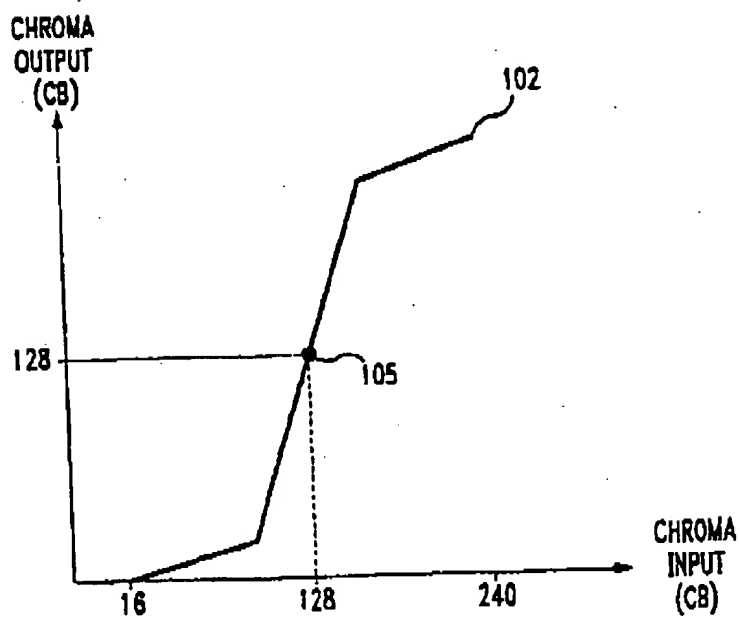


FIG. 7



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